CONSULTING REPORT
Kadena F-15 C/D Cost per Flying Hour Analysis
PROJECT MANAGERS: Capt Jeremy Howe and Capt Kevin Dawson
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BACKGROUND: Kadena AB is currently experiencing a higher number of F-15 C/D maintenance issues than other F-15 C/D bases. Mission Capable (MC) rates are consistently 20% lower than other F-15 C/D units, and Kadena AB failed to meet all 10 Air Force F-15 C/D maintenance standards from May through June[1]. In order to reverse current maintenance trends, PACAF is evaluating the idea of reducing Kadena AB F-15 C/D Average Sortie Duration (ASD) to reduce the number of flying hours accrued by each aircraft. However, PACAF believes reducing ASD will have a negative effect (increase) on the Cost per Flying Hour (CPFH) for Kadena's F-15 C/D fleet.

PROBLEM STATEMENT: Will reducing the ASD for Kadena AB F-15 C/Ds increase the CPFH for this Mission Design Series (MDS)?

OBJECTIVES: The primary objective is to determine the effect ASD has on CPFH for Kadena AB F-15 C/Ds. To accomplish this objective, the following secondary objectives must be accomplished:
- Define the CPFH model and the data used to compute hourly costs.
- Identify Air Force maintenance metrics used to represent component failures.
- Evaluate the factors contributing to component failure and reduced aircraft reliability.
- Through statistical analysis, establish a lack of correlation between ASD and component failures. This analysis is necessary to validate the assumptions used to estimate CPFH changes resulting from ASD variations.

METHODOLOGY: A review of related literature and Air Force regulations will be used to accomplish the first three secondary objectives. Regression analysis will be used to illustrate a lack of correlation between ASD and component failures using data from the PACAF REDCAP report (Oct 2000 through June 2005). Illustrating a lack of correlation between ASD and component failures will validate the following assumptions:
- If component failures are not correlated to ASD, then an airframe can be expected to experience the same number of component failures per sortie, regardless of sortie duration.
- If an airframe experiences the same number of component failures per sortie, the same amount of repair parts (consumable and repairable) will be required.
- If the same number of repair parts is required, the cost of parts will remain unchanged.

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[1] PACAF REDCAP report. https://redcap.hickam.af.mil/REDCAP2/welcome.aspx

Once these assumptions are validated, changes in CPFH can be calculated based on the following general assumptions:
- Modification costs will remain unchanged across all ASDs.
- The cost of aviation fuel will change linearly with changes in ASD. This assumption suggests that if ASD decreases by 10%, fuel consumption will also decrease by 10% and the resulting fuel costs will decrease by 10%. This assumption is a worst-case scenario, as fuel consumption will most likely not be linearly related to ASD due to the fact that excessive fuel burn is encountered during the takeoff phase of flight.
- For the purposes of valid cost comparison, paired scenarios must hold constant either the number of sorties or the number of hours flown. This is to ensure a fair comparison in the spirit of "apples to apples". For example, it would not be valid to compare a 1.65 ASD, 500-sortie scenario (825 flying hours) with a scenario of 1.5 ASD, 600 sorties (900 flying hours).

RESEARCH AND FINDINGS: Kimbrough[2] identified the three major cost variables of the aircraft CPFH calculation model to be aircraft parts, aviation fuel, and modifications/sustainment costs. Aircraft part costs for each fiscal year are broken down into consumable and repairable parts; however, this research aggregated this variable to simply aircraft parts. Aviation fuel represents the cost of avgas used throughout the fiscal year, and modifications/sustainment costs represent planned depot modifications and weapon system upgrades. CPFH is calculated by adding the three major cost variables and dividing by the number of hours flown throughout the fiscal year. Equation 1 illustrates this calculation.

$$\frac{PARTS + FUEL + MODIFICATIONS}{HOURS\,FLOWN} = CPFH$$

Equation 1. CPFH Calculation

Manuel[3] discovered that 70% of total aircraft flying program costs were attributed to repair parts, 19% were attributed to aviation fuel, and 11% were attributed to modifications/sustainment. Assuming these ratios can be applied to strategic CPFH models across any weapon system provides the ability to estimate CPFH changes based on ASD and the number of sorties flown.

Ebeling[4] identifies five different methods of inducing a failure: hourly operation time, operating cycles, clock time, failures on demand, and maintenance-induced failures. Component failures attributed to "hourly operation time" should experience fewer

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[2] Kimbrough, Anthony. Developing Cost per Flying Hour Factors for the Operations and Maintenance Phase of the Satellite Cost Cycle. Air Force Institute of Technology Thesis. March 2003.
[3] Manuel, Anthony. OPNAV N43 Flying Hour Program. Unpublished presentation from the ASO/ASC Conference. 3 – 5 May 2005.
[4] Ebeling, Charles E. An Introduction to Reliability and Maintainability Engineering. McGraw-Hill Book Co. 1997.

failures per sortie as ASD (and the resulting total operating time) is reduced. However, if the number of "low ASD" sorties is increased to achieve the same number of flying hours as the baseline ASD, the number of "hourly operation time" failures will remain unchanged. Components failing based on an "operating cycle" failure distribution fail based on the number of uses. Therefore, flying the same number of sorties with a lower ASD will result in approximately the same number of operating cycle failures. Increasing the number of "low ASD" sorties to accomplish a desired flying hour program will actually generate more component failures resulting in increased maintenance workload and parts cost. Components failing on a clock time failure distribution should experience the same number of failures regardless of ASD or the number of sorties flown.

Failures on demand occur when a system is turned on and used for the first time, and are represented by binomial probability distributions[5]. The "light bulb theory" has demonstrated that light bulbs (and many other electrical components[6]) have a higher probability of failure when activated, compared to operating under normal operational loads. If the number of sorties remains unchanged, the number of failures on demand - in this case, electrical failures as well as aircraft takeoffs and landings - should remain unchanged as well. Increasing the number of sorties will yield an increase in the number of failures on demand. Likewise, the number of maintenance induced failures should increase as the number of sorties flown increases because more maintenance is required to repair an increased number of component failures and perform additional thru-flights. A maintenance-induced failure is the binomial probability of a maintainer damaging a component during repair. The number of maintenance-induced failures increases as the amount of either scheduled or unscheduled maintenance increases.

Table 1 summarizes the effect of reducing ASD with respect to the number of component failures based on the different methods of inducing failures described above.

Table 1. Impact of ASD, Sorties Flown, and Flying Hours on Component Failures

Failure Rate Distribution	Lower ASD, Same Sorties (Reduced Flying Hrs)	Lower ASD, More Sorties (Constant Flying Hrs)
Operating Hours	Less	Same
Operating Cycles	Same	Increased
Clock Time	Same	Same
Failures on Demand	Same	Increased
Maintenance Induced	Same	Increased

It can be seen from Table 1 that reducing ASD only results in a lower number of component failures when the number of sorties flown remains unchanged. Increasing the number of "low ASD sorties" to achieve the baseline flying hour program will result in an increase in the number of component failures for three of the five different failure induction methods.

[5] ibid.
[6] ibid.

The number of failures will remain unchanged for components failing on an operating hour distribution; therefore, these failures will not increase total aircraft operating costs for comparable flying hours. However, it is important to identify metrics capable of examining failures based on operating cycles, failures on demand, and maintenance induced failures. The number of component failures attributed to these methods can be expected to increase as the number of sorties increases. As a result, total aircraft operating costs will increase.

Of the numerous maintenance metrics tracked by the Air Force, three are of primary interest: break rate, pilot reported discrepancies (PRD), and ground abort rate. A secondary maintenance metric of interest is total non-mission capable for maintenance (TNMCM) time.

Aircraft break rate represents the number of Code 3 breaks divided by the total number of sorties flown.[7] The break rate is "an indicator of aircraft system reliability. . . and is an excellent predictor of parts demand.[8]" A sortie is considered as one operational cycle for an aircraft at the strategic level, and break rates capture the number of grounding breaks per sortie. Break rates convey an expected number of "breaks" per operational cycle, and can supply data for components failing on an operating cycle failure distribution. As previously stated, total hours flown will remain the same; therefore, the number of component failures resulting from operational hour failure distributions should remain unchanged. PRDs can also be used as an indicator of breaks, and account for most Code 2 breaks and delayed discrepancies.

When an aircrew accepts an aircraft and then encounters a grounding maintenance condition, a ground abort occurs. Basically, an aircraft subsystem did not fail until it was placed under an operational load by the aircrew. Preflights and thru-flights will test most systems for operability, however many will be turned off until crew arrival. Therefore, ground abort rates are the most suitable data source for identifying failures on demand.

Based on the reliability theory depicted in Table 1, the number of component failures should increase as the number of sorties flown increases. The hypothesis for this research was that the number of failures would increase at an amount proportional to the break rate. For example, a unit flying 100 sorties with a 15% break rate can expect to experience 15 failures. Flying 200 sorties should then result in approximately 30 failures. As the number of sorties increase, PRDs should also increase. TNMCM time should increase as well due to the added repair actions resulting from an increased number of component failures.

To respond to the problem statement, this study attempts to prove ASD has little to no impact on the break rate and number of PRDs reported. If ASD is correlated to break rate and PRDs, we cannot safely assume aircraft (strategically speaking) fail on a cyclical basis (per sortie), as extended sorties may induce additional wear and tear on

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[7] Air Force Maintenance Metrics, Air Force Logistics Management Agency, 2001.
[8] ibid.

components. However, a lack of correlation between ASD and both break rate and PRD's validates the aforementioned assumption.

Figure 1 shows the correlation matrices for PACAF F-15 C/D maintenance data, delineated by command and base. These matrices show no direct relationship between ASD and break rate, nor show a direct relationship between ASD and the number of PRDs. Regression analysis confirmed a lack of correlation with an R^2 value of .1851 for ASD to break rate, and an R^2 of .0079 for ASD to PRDs. Therefore, it can be said that changes to ASD are unlikely to bear witness to changes in break rate or the number of PRDs. This being said, the number of breaks will increase as the number of sorties increases, however the rate at which the aircraft break remains unchanged.
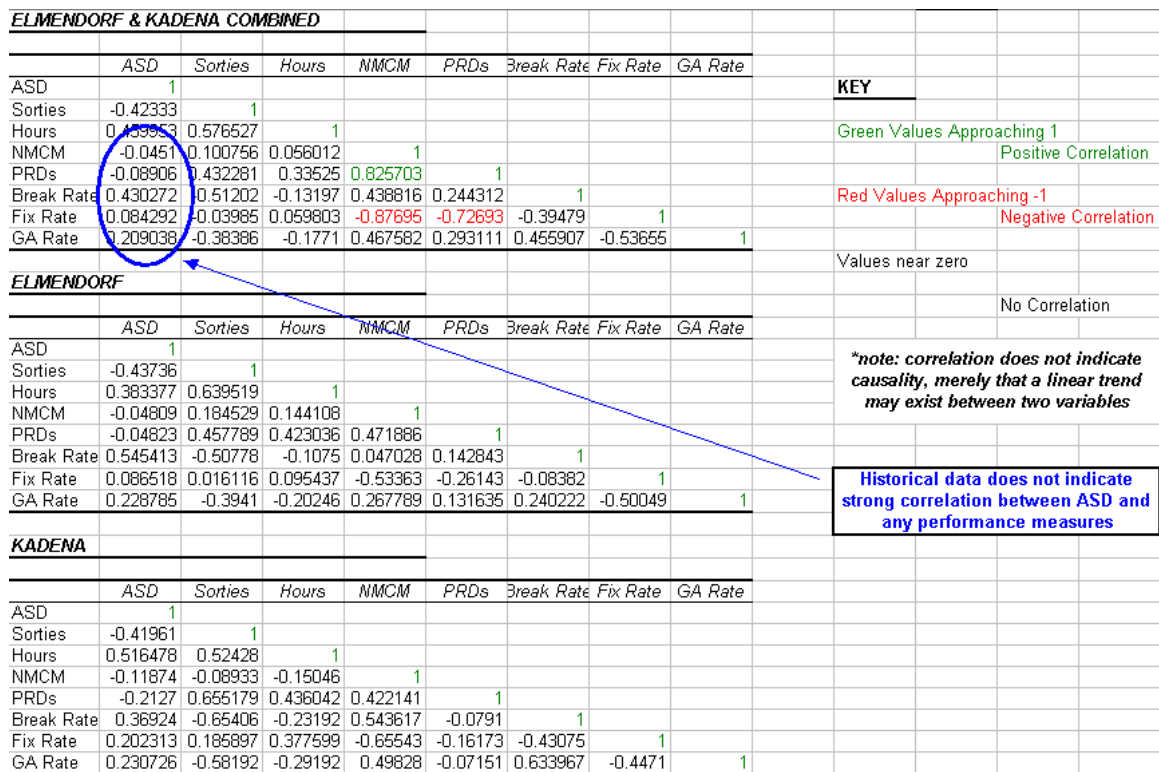
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	ASD	Sorties	Hours	NMCM	PRDs	Break Rate	Fix Rate	GA Rate
ASD	1							
Sorties	-0.42333	1						
Hours	0.439953	0.576527	1					
NMCM	-0.0451	0.100756	0.056012	1				
PRDs	-0.08906	0.432281	0.33525	0.825703	1			
Break Rate	0.430272	-0.51202	-0.13197	0.438816	0.244312	1		
Fix Rate	0.084292	-0.03985	0.059803	-0.87695	-0.72693	-0.39479	1	
GA Rate	0.209038	-0.38386	-0.1771	0.467582	0.293111	0.455907	-0.53655	1

ELMENDORF

	ASD	Sorties	Hours	NMCM	PRDs	Break Rate	Fix Rate	GA Rate
ASD	1							
Sorties	-0.43736	1						
Hours	0.383377	0.639519	1					
NMCM	-0.04809	0.184529	0.144108	1				
PRDs	-0.04823	0.457789	0.423036	0.471886	1			
Break Rate	0.545413	-0.50778	-0.1075	0.047028	0.142843	1		
Fix Rate	0.086518	0.016116	0.095437	-0.53363	-0.26143	-0.08382	1	
GA Rate	0.228785	-0.3941	-0.20246	0.267789	0.131635	0.240222	-0.50049	1

KADENA

	ASD	Sorties	Hours	NMCM	PRDs	Break Rate	Fix Rate	GA Rate
ASD	1							
Sorties	-0.41961	1						
Hours	0.516478	0.52428	1					
NMCM	-0.11874	-0.08933	-0.15046	1				
PRDs	-0.2127	0.655179	0.436042	0.422141	1			
Break Rate	0.36924	-0.65406	-0.23192	0.543617	-0.0791	1		
Fix Rate	0.202313	0.185897	0.377599	-0.65543	-0.16173	-0.43075	1	
GA Rate	0.230726	-0.58192	-0.29192	0.49828	-0.07151	0.633967	-0.4471	1

KEY

Green Values Approaching 1 — Positive Correlation

Red Values Approaching -1 — Negative Correlation

Values near zero — No Correlation

note: correlation does not indicate causality, merely that a linear trend may exist between two variables

Historical data does not indicate strong correlation between ASD and any performance measures

Figure 1. Correlation Matrices for PACAF F-15 C/D Maintenance Data

Flying Hours Held Constant

If ASD is reduced but the number of sorties increase to maintain a desired flying hour program, the number of "breaks" (Code 2 and 3) will increase, and the parts required to repair these "breaks" will also increase. The presumed increase would be linear and proportional to the increased number of breaks. Having established that the break rate remains relatively unaffected by ASD, it is valid to assume it will remain unchanged and produce additional breaks proportional to the increase in sorties flown. For this model, the assumption is the cost of parts will increase proportionally to sorties flown. Depot modifications and equipment upgrades are planned and scheduled on a fiscal year basis, independent of sorties and flying hours; therefore, the assumption can be safely made that

the cost of modifications will also remain more or less the same over time regardless of ASD or number of sorties flown. Due to the fact that the number of flying hours remains constant, we will assume the cost for fuel remains unchanged; however, we believe this cost should increase as more fuel is being expended during the increased number of takeoffs. Referring to Equation 1, the increased cost for repair parts will increase the numerator value, while all other variables (including the denominator) remain unchanged. With the numerator increasing, and the denominator held constant, solving by inspection alone will show an increase in CPFH. This model is represented in Figure 2, and although the data used in this research was notional ($6000 original CPFH for a 1.5 ASD), the same trends are experienced no matter what cost data is used: ***CPFH increased as ASD was reduced.***

Impact of ASD on CPFH: Variable ASD, Variable # of Sorties, Same Flying Hours

ASD	CPFH

(chart showing CPFH on y-axis from 0.00 to 8000.00, ASD on x-axis from 1.9 to 1.1, with an increasing curve from ~5000 at ASD 1.9 to ~7500 at ASD 1.1)
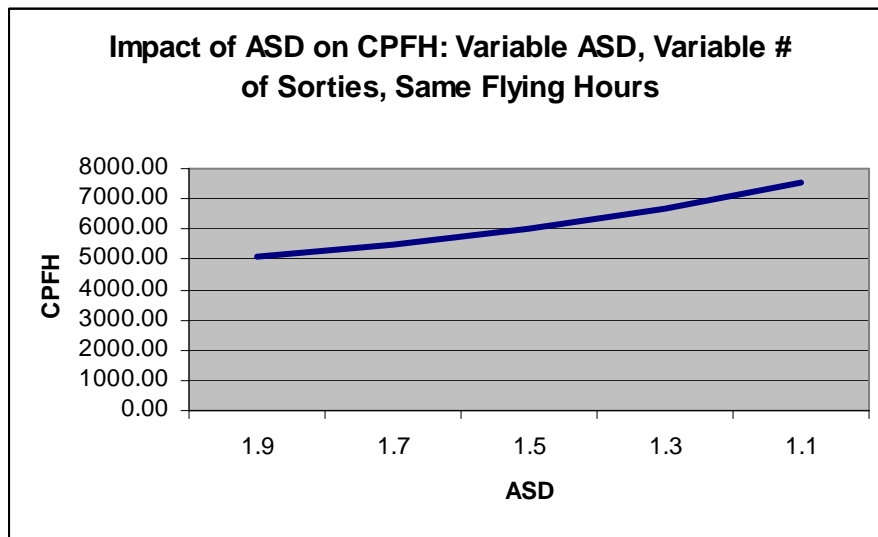
Figure 2. CPFH Estimates: Variable ASD, Variable Number of Sorties, Same Flying Hours

Sorties Held Constant

If the same number of sorties is flown over different ASDs, the number of "breaks" (Code 2 and 3) will remain unchanged, and the parts required to repair these "breaks" will also remain unchanged. Furthermore, if the repair parts required remain unaffected by changes in ASD, the cost of parts should remain relatively the same. Depot modifications and equipment upgrades are planned and scheduled on a fiscal year basis, independent of sorties and flying hours, therefore, we can safely make the assumption that the cost of modifications will also remain more or less the same over time regardless of ASD or number of sorties flown. As such, when measuring the effect of ASD changes on CPFH, we can hold constant the cost of parts and cost of modifications. With reduced ASDs, it follows that we will observe reductions in quantity of gas consumed and total hours flown. Under a worst-case scenario, we could assume a perfectly linear relationship between gas used (and consequently, cost of gas) and hours flown. For this model, the cost of gas was assumed to decrease proportionally to the reduction in flying hours (i.e. 10% less flying hours results in 10% less fuel costs). Realistically, more fuel is likely

expended at takeoff versus level flight, but for the purposes of this analysis, we assume a linear relationship. Since the number of flying hours is simply a manipulation of ASD (that is, ASD * # of sorties), the same logic can be applied to ASD reduction. Again, referring to Equation 1, the numerator is increasing while the denominator is decreasing. Therefore, a direct comparison can be made between CPFH calculations for different ASDs. Due to the lack of operational data, notional cost data was used to populate the model represented in Figure 3. The numerical values of the CPFH change however the trend established in Figure 2 remains constant: *CPFH increased as ASD was reduced.*

Impact of ASD on CPFH: Reduced ASD, Same # of Sorties, Reduced Flying Hours
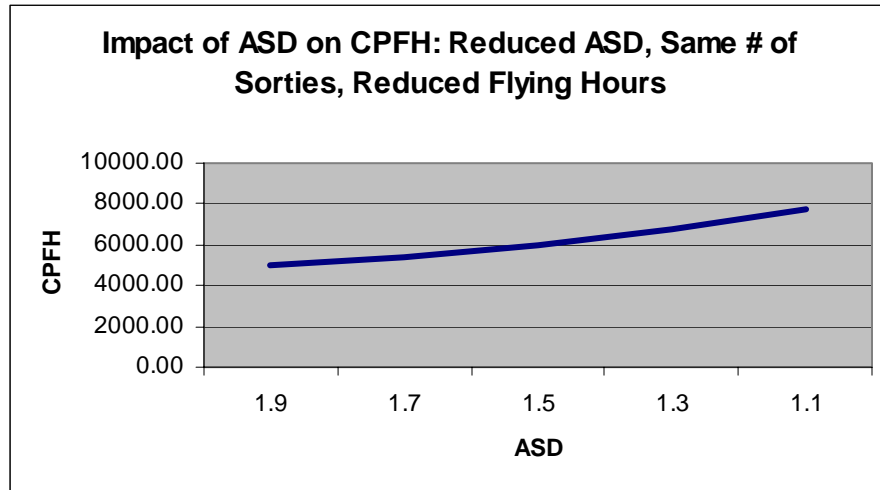
Figure 3. CPFH Estimates: Variable ASD, Same Number of Sorties, Variable Flying Hours

CONCLUSIONS AND RECOMMENDATIONS: The findings of this research show that CPFH will increase as ASD decreases, irrespective of the amount of sorties or hours flown. The analysis indicates that reducing ASD cannot decrease the cost of aircraft repair parts, which accounts for approximately 70% of the total flying hour program costs. Reducing ASD and pursuing the same flying hour program increases the cost of repair parts and significantly contributes to an increased CPFH. This scenario will require more maintenance effort to generate additional sorties, and will require more maintenance effort to repair the additional aircraft "breaks."

POINTS OF CONTACT: **Capt Jeremy Howe and Capt Kevin Dawson
AFLMA/LGM
501 Ward Street
Maxwell AFB – Gunter Annex, AL 36114
Comm (334) 416-1850   DSN 596-1850**

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14. ABSTRACT

Although largely focused on illustrating the impact of Average Sortie Duration (ASD) changes on Cost per Flying Hour (CPFH) calculations, this study was also an effort to broadly examine the variety of component failure modes and their influence on aircraft break events during sorties. In conjunction with a notional CPFH calculation model, correlation and regression techniques were used to examine historical PACAF F-15C/D maintenance data, to include Break Rate, Pilot Reported Discrepancies (PRD) and Total Non-mission Capable for Maintenance (TNMCM) time. The findings of this research indicate that CPFH will increase as ASD decreases, irrespective of the amount of sorties or hours flown.

15. SUBJECT TERMS
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